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NAVAL POSTGRADUATE SCHOOL

Monterey, California

NON-EQUILIBRIUM EFFECTS IN FAST MOVING PLASMAS

by

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Contents

Annual Summary Report

NR 099 - 400, Project Order PO 2 - 0193

Non-Equilibrium Effects in Fast Moving Plasmas

This report summarizes the research done at the Naval Postgraduate School on laser produced plasmas. The objective of this past year's research was to investigate the dependence of self-generated magnetic fields on the dynamics of the laser produced plasma, laser power density, and ambient background pressure. The spatial and temporal variations of the self-generated magnetic fields were mapped extensively. Reversal of the spontaneous magnetic field associated with the expanding laser produced plasma has been found at times later than the cessation of the laser pulse. This indicates the generation of magnetic fields by the dynamics of the plasma, independently of the laser-target interaction.

SELF-GENERATED MAGNETIC FIELDS IN LASER PRODUCED PLASMAS

In studying the generation of plasmas by lasers, it has been generally assumed that the only magnetic field present was the externally applied field. However, magnetic fields may spontaneously arise in a fast streaming plasma when inhomogeneities occur with nonaligned density and temperature gradients. These magnetic fields may be quite large in the focal spot region and thus influence the dynamics and heat conduction of the electrons and the coupling of the expanding plasma to a bias magnetic field.

The equation describing the development of the magnetic fields is obtained from the generalized Ohm's law,

$$\vec{J} = \sigma(\vec{E} + \vec{V}_e \times \vec{B} + \frac{1}{en_e} \nabla\vec{P}_e) \qquad (1)$$

where all quantities have their conventional meanings and the subscript e refers to the electron component of that quantity. Using the Maxwell curl equation this can be written in the form

$$\frac{\partial\vec{B}}{\partial t} = \vec{\nabla}\times(\vec{V}_e \times \vec{B}) + \frac{1}{\mu_o\sigma}\nabla^2\vec{B} + \frac{K}{en_e}\vec{\nabla}T_e \times \vec{\nabla}n_e \qquad (2)$$

The first two terms on the right hand side are the flow and diffusion terms; the generation of a magnetic field requires that the last term, the source term S, shall be non-zero. Anisotropies in the electron density and temperature gradients lead to the occurrence of spontaneous magnetic fields in the plasma. Such spontaneous magnetic fields have been observed in laser plasmas in the absence of applied fields[1,2,3]. Stamper, et al[3], have suggested that these spontaneous fields result from thermo-electric currents associated with gradients in temperature and pressure occurring during the early stages of formation and heating of a plasma by a giant laser pulse.

According to the source term in Eq. (2)

$$\vec{S} = \frac{k}{en_e}\vec{\nabla}T_e \times \vec{\nabla}n_e \qquad (3)$$

no field generation will occur unless ∇T_e and ∇n_e are nonparallel. The geometry of the magnetic field is determined by the geometry of the laser produced plasma. A plasma produced by laser impact on a planar target expands in the direction of the target normal and is axisymmetric about its expansion direction so that there are no azimuthal density or temperature gradients. Then according to Eq. (3), the field will be generated entirely in the azimuthal direction and will be symmetric about the normal. During the laser heating of the plasma, the largest contribution to the source term comes from a temperature gradient in the negative radial direction and the density gradient due to the expansion of the plasma in direction of the target normal. The temperature gradient is a consequence of the finite radial extent of the laser beam and arises near the radial edge of the focal spot. This combination of ∇T_e and ∇n_e will generate magnetic field in the azimuthal direction as observed initially[4] (Appendix A).

The strongest field production can be expected to occur at the front of the expanding laser plasma, since the quantity $\frac{1}{n_e} \nabla n_e$ in Eq. (3) is largest there[5]. Since this is also the region where the laser plasma and the ambient photoionized background will interact, it is possible for the background to influence the generation of the fields.

EXPERIMENTAL RESULTS

The beam from a 300 MW (25 nsec) neodymium-glass laser was focused at a 30° incident angle onto a mylar or aluminum disc target in a cylindrical polar coordinate system centered on the burn spot with z axis along the target normal. The magnetic field was analyzed with magnetic inductive probes about 1 mm in diameter. Electric double probes were used to study the density variations of the laser plasma.

The azimuthal spontaneous magnetic field has been mapped extensively. Figure 1 shows the contour plots of B_θ detected at each point in the plane for ambient nitrogen pressures of 0.1, 5.0 and 250 mTorr. In these plots, the foil target is located at the left edge of the plot, and is perpendicular to the plane of the figure. The laser beam comes in from the right at 30° to the plane of the figure and strikes the target at a lower left hand corner of the plot. The resulting laser plasma then expands to the right. The region where the laser beam intersects the plane of the plots cannot be probed without interfering with the incident beam, and is left blank. The direction of the magnetic field is into the plane of Figure 1. The contour lines connect points at which the magnitude of B_θ is the same. Mapping the field at positions not in the plane of the contour plots established that the azimuthal magnetic field was axisymmetrical about the target normal. Hence, the contour plots give full three-dimensional representations of the fields if they are rotated about the target normal.

The field measurements were also time-resolved to study the temporal variations; the contour plots derived from these measurements show that the magnetic field, like the laser plasma, expands and propagates outward from the target. The propagation velocity of the peak field is about 10^7 cm/sec for ambient pressures of 0.1 and 5 mTorr of nitrogen and about 6.5×10^6 cm/sec for 250 mTorr.

Figure 2 shows the current density flow pattern derived from the magnetic field data at 120 nsec for 250 mTorr of nitrogen. The strongest current flow is along the target normal and has a magnitude of 612 amps/cm^2. The current flow pattern is toroidal in three dimensions, with no current flowing in the azimuthal direction. It should be noted here that the front of the expanding laser-produced plasma has propagated to a distance of about 0.8 cm in the axial and 0.4 cm in the radial direction. It is obvious from Fig. 2 that the current is flowing through the photoionized background plasma as well as through the laser plasma.

The strength of the self-generated magnetic field was found to depend quite strongly on the ambient pressure of the background gas (Fig. 1 of reference 5); (Appendix B). This figure shows the way in which the peak azimuthal magnetic field detected at fixed position depends on the background nitrogen pressure for aluminum and mylar targets. Three separate regions are evident in this figure. At pressures lower than 1 mTorr, the magnitude of B_θ is independent of pressure but dependent on target material. For pressures between 1 mTorr and 200 mTorr, the field magnitude increases considerably above the low-pressure value. In this region the coupling of the background with the laser plasma directly influences the source term S of Eq. (3). This influence can be expressed by writing the source term

$$S = \frac{K}{en_e} \vec{\nabla} T_e \times \nabla n_e \text{ in the form } \frac{K(\nabla T)_r}{e\delta} \text{ where } (\nabla T)_r$$

is the radial temperature gradient, here in the negative radial direction, and

$$\frac{\nabla n_e}{n_e} \simeq \frac{1}{\delta}$$

is inversely proportional to the front thickness of the laser plasma. The density gradient is in the negative z direction. As the background pressure increases, δ decreases, as the front of the streaming laser plasma steepens due to momentum coupling with the background plasma.

From Eq. (3) it also follows that the source term reverses its sign if the direction of the temperature or the density gradient is reversed. It should be possible to create azimuthal magnetic fields in a direction opposite to the initial fields by reversing the direction of the source term density gradient at late times. in the plasma expansion. Magnetic field reversal has been observed several hundred nanoseconds after shut off of the laser pulse. The field reversal was produced by allowing the expanding laser plasma to impinge on a glass plate placed at 1.15 cm from the target. The resultant pile up of the plasma caused production of azimuthal magnetic fields in a direction opposite to the initial fields; see Fig. 3 of reference 5; (Appendix B). The appearance of magnetic field of reversed sign at later time is evidence of field generation several hundred nanoseconds after laser shutoff.

It may be assumed that magnetic fields can be generated in the absence of laser radiation in fast plasma streamers if non-parallel temperature and density gradients are set up due to an interaction with a background plasma.

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References 4 and 5 are attached to this report as Appendices A and B.

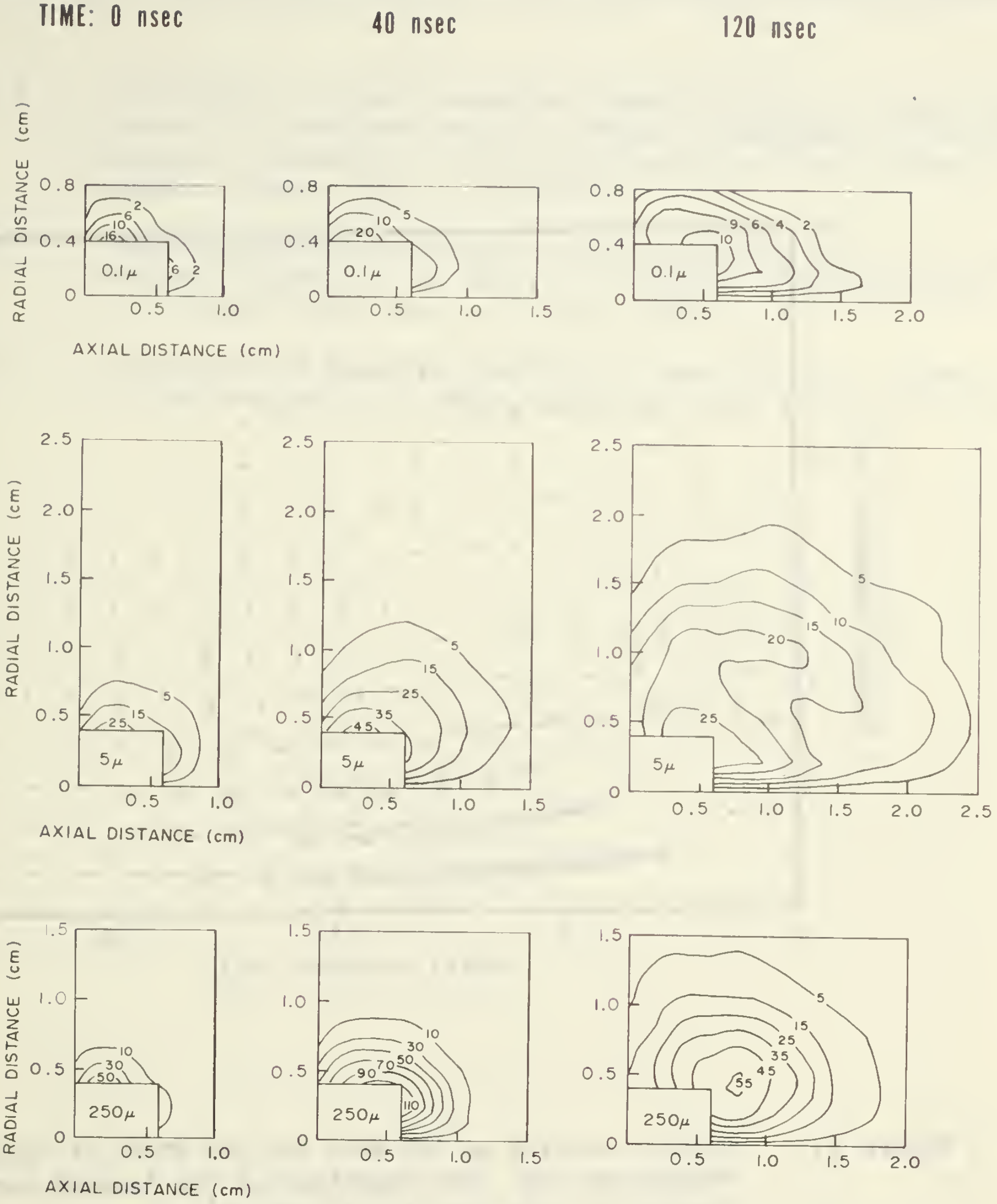

Figure 1. Magnetic field contours at the maximum of the laser pulse, reference time = 0 nsec, 40 nsec later and at 120 nsec for pressures of 0.1 μ, 5 μ and 250 μ of nitrogen background gas and a mylar target. A positive number gives the magnitude of the B-field in gauss and the direction is into the plane of the contour plots.

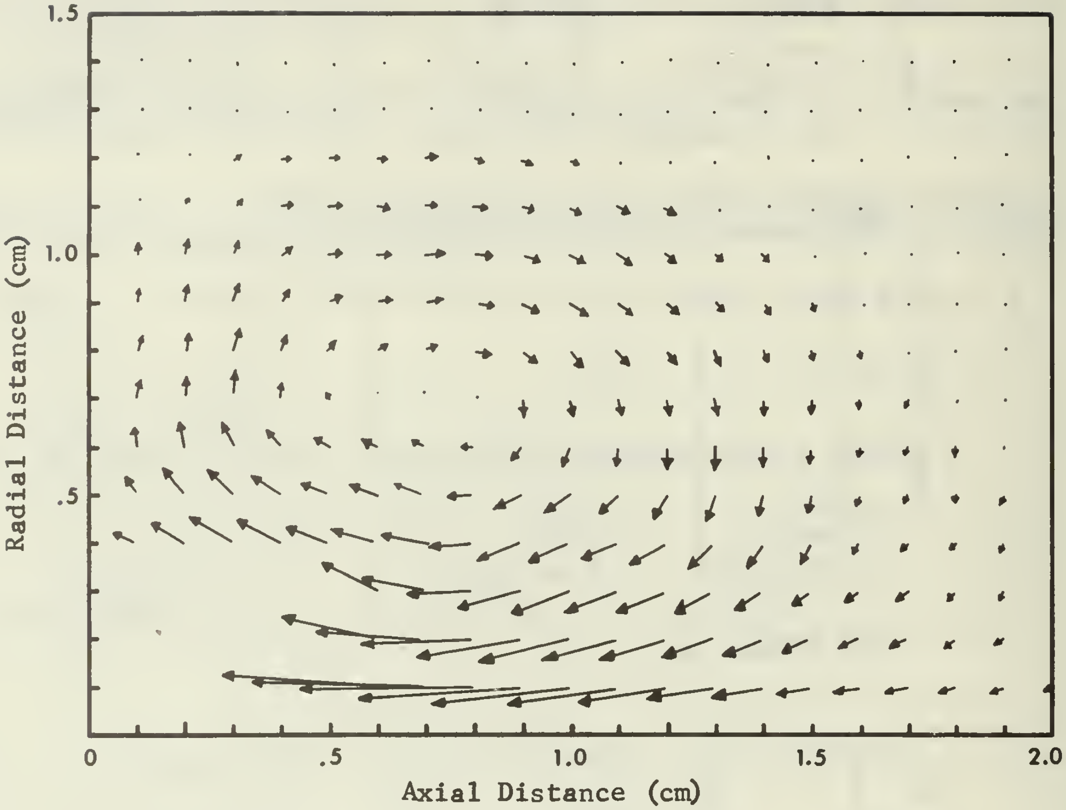

Figure 2. Current density at 120 nsec for 250 mTorr of nitrogen background gas. The magnitude of the largest current density at this time is 612 amp/cm^2.

PUBLICATIONS

Following is a list of papers and abstracts published during the reporting period.

Appendix A	"Investigation of Self-Generated Magnetic Fields in Laser Produced Plasmas," F. Schwirzke and L. L. McKee, Proceedings of the Fifth European Conference on Controlled Fusion and Plasma Physics, Grenoble, France, Vol. I, 63 (1972).
Appendix B	"Pressure Dependence of Self-Generated Magnetic Fields in Laser-Produced Plasmas," R. S. Bird, L. L. McKee, F. Schwirzke and A. W. Cooper, Phys. Rev. A, 7, 1328 (1973).
Appendix C	"Self-Generated Magnetic Fields in a Laser Produced Plasma," F. Schwirzke and L. L. McKee, Bull. Am. Phys. Soc. 17, 1027 (1972).

FIFTH EUROPEAN CONFERENCE ON CONTROLLED FUSION AND PLASMA PHYSICS

GRENOBLE FRANCE AUGUST 21-25 1972

VOL. 1

CONTRIBUTED PAPER No. 63

INVESTIGATION OF SELF-GENERATED MAGNETIC FIELDS IN LASER PRODUCED PLASMAS

by
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Abstract: The dynamics of a laser produced plasma and the dependence of the self-generated magnetic fields on position, time, laser power density, and ambient background pressure has been investigated. Electrons and ions can not separate when the laser produced plasma expands into a high vacuum. With a background gas the laser heated electrons can stream freely out of the laser heated region, through the photo-ionized background plasma and considerably higher magnetic fields are generated.

A hot dense plasma is produced in the initial phase of the impact of a high power laser pulse on a solid target. Further absorption of the laser radiation and reflection occur in a plasma layer in front of the target. Radiative transport of the laser energy is cut off in the overdense plasma and heat conduction by electrons becomes the principal mechanism of energy transfer from the laser heated plasma layer to the target. Anisotropies in the electron density and temperature gradients or large scale turbulence in the expanding, laser produced plasma can lead to the occurrence of spontaneous magnetic fields. These fields can influence the electronic heat conduction and the dynamics of the plasma.

References [1-4] reported observing spontaneous magnetic fields associated with a laser produced plasma. The spontaneous magnetic fields were generated in the absence of external applied magnetic fields and are mainly in the azimuthal direction with reference to the target normal. This component of the magnetic field corresponds to an electron current which travels out from the target along the normal. Only a brief study of the dependence of the self-generated magnetic fields on plasma and laser parameters was published in [3] so we mapped the magnetic fields as function of time and laser power for a better understanding of the generating mechanism. The primary parameters upon which the magnetic fields were found to depend were position, laser power density at the target's surface and ambient background pressure of nitrogen gas.

A single stage amplified neodymium-doped glass laser was used with an output of up to 450 MW (11 Joules in 24 nsec). The target consisted of a Mylar foil disk .005 in thick and about 5 cm in diameter. The foil could be rotated to allow many shots to be made on a given foil. The vacuum chamber in which the target was located was specially designed to facilitate the detection of the fields. The laser beam entered the chamber and struck the target at an angle of 30° with respect to the normal and to the target and so that the laser beam and normal were both in a horizontal plane. This angle was chosen so that the plasma which streamed normally out from the target surface could be directly probed along the normal without having the laser beam strike the probes. Diagnostics were performed with small (∿2mm diameter) inductive magnetic probes. They were accurately calibrated by insertion into carefully wound Helmholtz coils. In order to insure that the probe data was meaningful, they were rotated by 180°, and the probe signal was checked to make sure that it reversed in polarity. The probe signals, which are proportional to dB/dt, were integrated by means of an RC integrator before being displayed on the oscilloscope.

The magnetic probe signals were well defined pulses of fast rise (typically 50 nsec) and relatively slower decay (typically 250 nsec). The arrival of the magnetic field at the position of the probe was found to correspond to the arrival of the outwardly streaming laser plasma - the probe signal started at a later time relative to the laser pulse as the probe distance from the laser focal spot was increased. This delay in time corresponded to the expansion velocity of the laser plasma of about 10^7 cm/sec. As the distance out from the target increased, the duration of the probe signal also increased, indicating that the magnetic field became spatially more diffuse as it travelled out with the plasma. A spatial mapping of the field showed that the azimuthal field was circularly symmetric about the normal. Since the plasma streams normally out from the surface of the target, this is to be expected. At distances larger than 3mm from the surface along the normal, the maximum field decreased exponentially at a pressure of 250 mTorr from a maximum value of 220 Gauss, Figure 1. At distances closer than 3mm the field also decreased from this maximum as the distance to the surface decreased. At a given distance out along the normal, the field also decreased exponentially as the probe was moved up to larger distances from the normal. These experimental results show that the self-generated fields do not scale with 1/r to extremely large values at small focal spot radius. The location of the maximum of the B field, 3-4 mm in front of the target, probably coincides with a position in the density profile where the laser and plasma frequency are of the same order and strong plasma heating occurs locally.

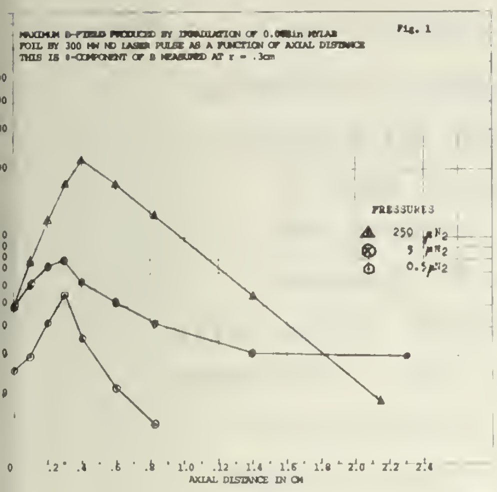
Fig. 1

MAXIMUM B-FIELD PRODUCED BY IRRADIATION OF 0.005in MYLAR FOIL BY 300 MW ND LASER PULSE AS A FUNCTION OF AXIAL DISTANCE THIS IS θ-COMPONENT OF B MEASURED AT r = .3cm

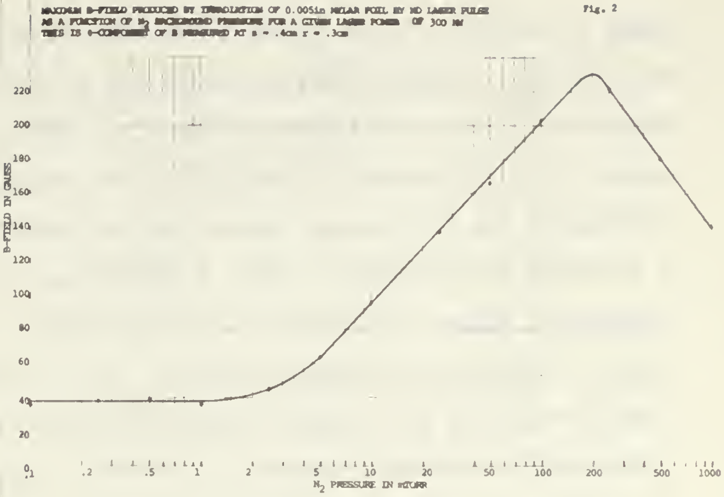
Fig. 2

MAXIMUM B-FIELD PRODUCED BY IRRADIATION OF 0.005in MYLAR FOIL BY ND LASER PULSE AS A FUNCTION OF N_2 BACKGROUND PRESSURE FOR A GIVEN LASER POWER OF 300 MW THIS IS θ-COMPONENT OF B MEASURED AT z = .4cm r = .3cm

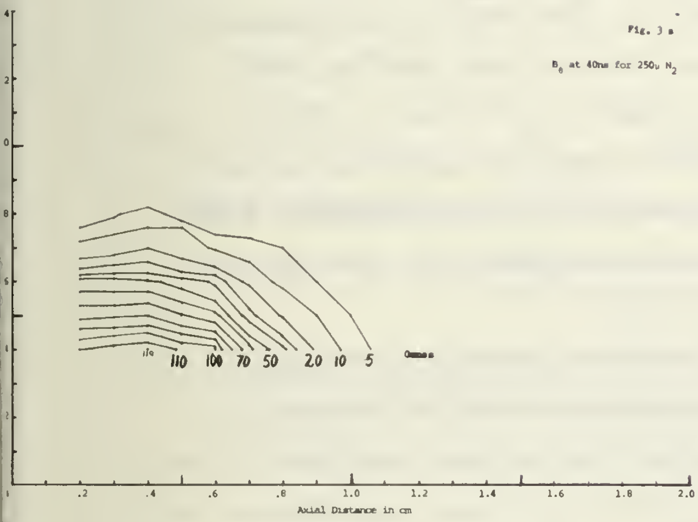
Fig. 3 a

B_θ at 40ns for 250μ N_2

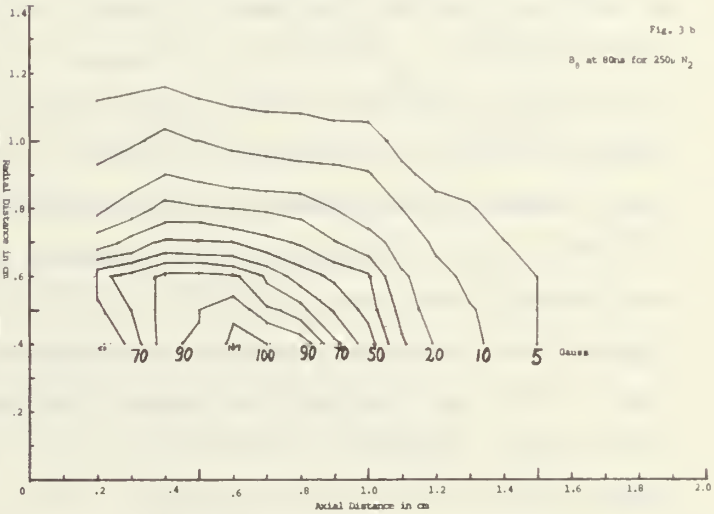
Fig. 3 b

B_θ at 80ns for 250μ N_2

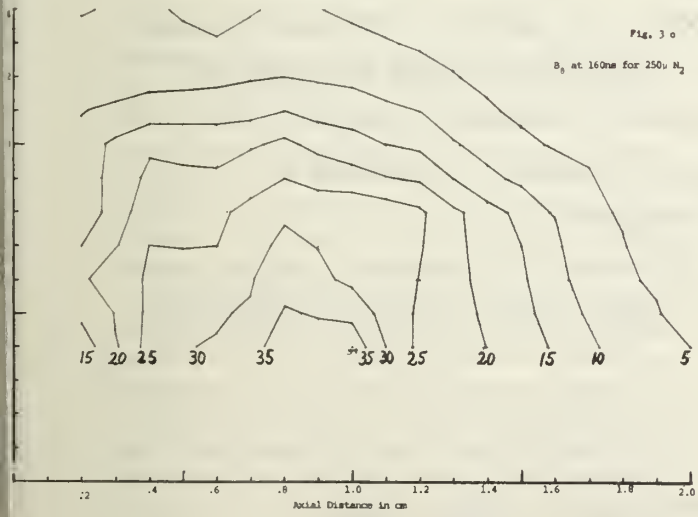
Fig. 3 c

B_θ at 160ns for 250μ N_2

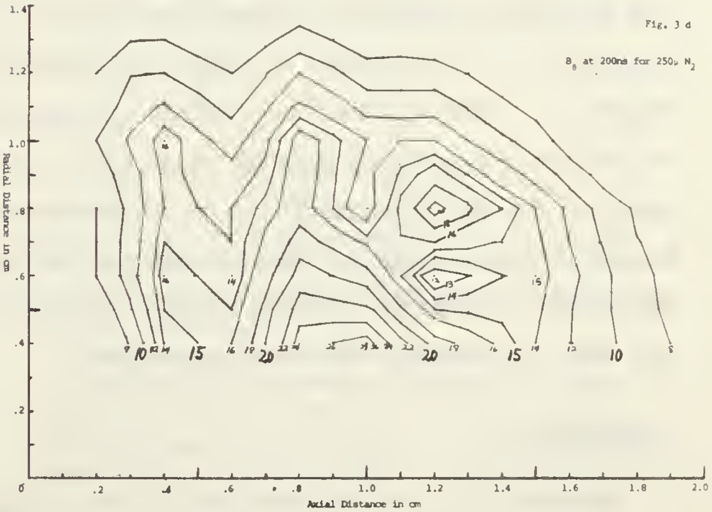
Fig. 3 d

B_θ at 200ns for 250μ N_2

Most important, at a given position, the strength of the magnetic fields was found to depend quite strongly on the background pressure of nitrogen, Figure 2. At a position of 4mm in front of the target and 3mm above the normal to the target, the field was amplified by a factor of about 6 (38 Gauss to 210 Gauss) when the nitrogen pressure was increased from 0.1 mTorr to 200 mTorr, for a laser power of 300 MW. As the pressure increased above 200 mTorr to 1000 mTorr, the field was damped exponentially with increasing pressure, due to the increased collision rate. This strong interaction of the laser plasma with the background gas is actually an interaction between counter streaming plasmas because the background gas is photoionized by the laser plasma's radiation. The density in the background plasma, $n_e \sim 10^{15} cm^{-3}$, is several orders of magnitude smaller than the critical density in the laser generated plasma, $n_e \sim 10^{21} cm^{-3}$. This indicates that the background plasma can hardly damp the expansion of the laser plasma. The reason for the amplification of the fields between 1 and 200 mTorr then seems to be that a larger electric current can flow through the ionized background plasma.

Figures 3a-d show the contours of constant magnetic induction as function of time, at 40, 80, 160 and 200 nsec. The horizontal axis with the axial distance scale represents the normal to the target foil at the focal spot O and hence this is the axis of symmetry. The B_θ-field lines are perpendicular to the contour lines with direction into the paper. B_θ goes to zero and changes direction if the magnetic probe is moved in r-direction across the axis of symmetry. The Figures 3a-d show how the B-field is carried along with the expanding plasma and damped with time. Figure 3d seems to indicate a breakup of the expansion by an interchange instability.

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Appendix B

PHYSICAL REVIEW A VOLUME 7, NUMBER 4 APRIL 1973

Pressure Dependence of Self-Generated Magnetic Fields in Laser-Produced Plasmas*

R. S. Bird, L. L. McKee,† F. Schwirzke, and A. W. Cooper
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(Received 5 September 1972)

The systematic dependence of the magnitude of the self-generated magnetic fields of a laser-produced plasma on nitrogen background pressure has been investigated. At expansion distances of a few millimeters or more, the strongest fields were found to reside at the front of the streaming laser plasma. Magnetic fields were created in the laser plasma long after laser shut off by allowing the streaming plasma to impinge upon a glass plate.

Magnetic fields spontaneously generated in the absence of applied fields have been observed in several experiments with laser-produced plasmas.[1–3] Stamper *et al.*[3] have suggested that these spontaneous fields result from thermo-electric currents associated with temperature and pressure gradients existing during the early stages of the formation and heating of a plasma by a giant laser pulse.

We have made a systematic study of the dependence of the spontaneous magnetic fields on the pressure of the background gas which indicates that magnetic fields are generated by pressure gradients in the front of the expanding laser plasma. Field amplification or field reversal can be caused by increase or reversal of the pressure gradients in the plasma front long after the end of the laser pulse.

The equation describing the development of the magnetic fields is obtained from the generalized Ohm's law

$$\vec{J} = \sigma\left[\vec{E} + \vec{V}_e \times \vec{B} + (1/en_e)\,\nabla P_e\right], \qquad (1)$$

where all quantities have their conventional meaning and the subscript e refers to the electron component of that quantity. Solving for $\vec{E}$ and using

$$\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$$

gives

$$\frac{\partial \vec{B}}{\partial t} = \nabla \times (\vec{V}_e \times \vec{B}) + \frac{1}{\mu_0 \sigma}\,\nabla^2 \vec{B} + \frac{k}{en_e}\,\nabla T_e \times \nabla n_e\,. \qquad (2)$$

The first two terms on the right-hand side are the flow and diffusion terms. The generation of a magnetic field requires that the last term, the source term $\vec{S}$, be nonzero.

The beam from a 300-MW (7.5 J in 25 nsec) neodymium-doped glass laser was focused by a lens with a 28-cm focal length. The principal targets were aluminum and Mylar discs. The laser irradiation produced a 2-mm hole in the Mylar (disc thickness 0.01 cm) but did not penetrate the aluminum. The laser beam entered a vacuum chamber and struck the target at an angle of 30° with respect to the target normal. The resultant plasma streamed out along the target normal[4] defining a convenient cylindrical-polar coordinate system with the z axis along the target normal, the $\theta = 0°$ line vertically up, and the origin centered on the burn spot. The magnetic field was analyzed with small

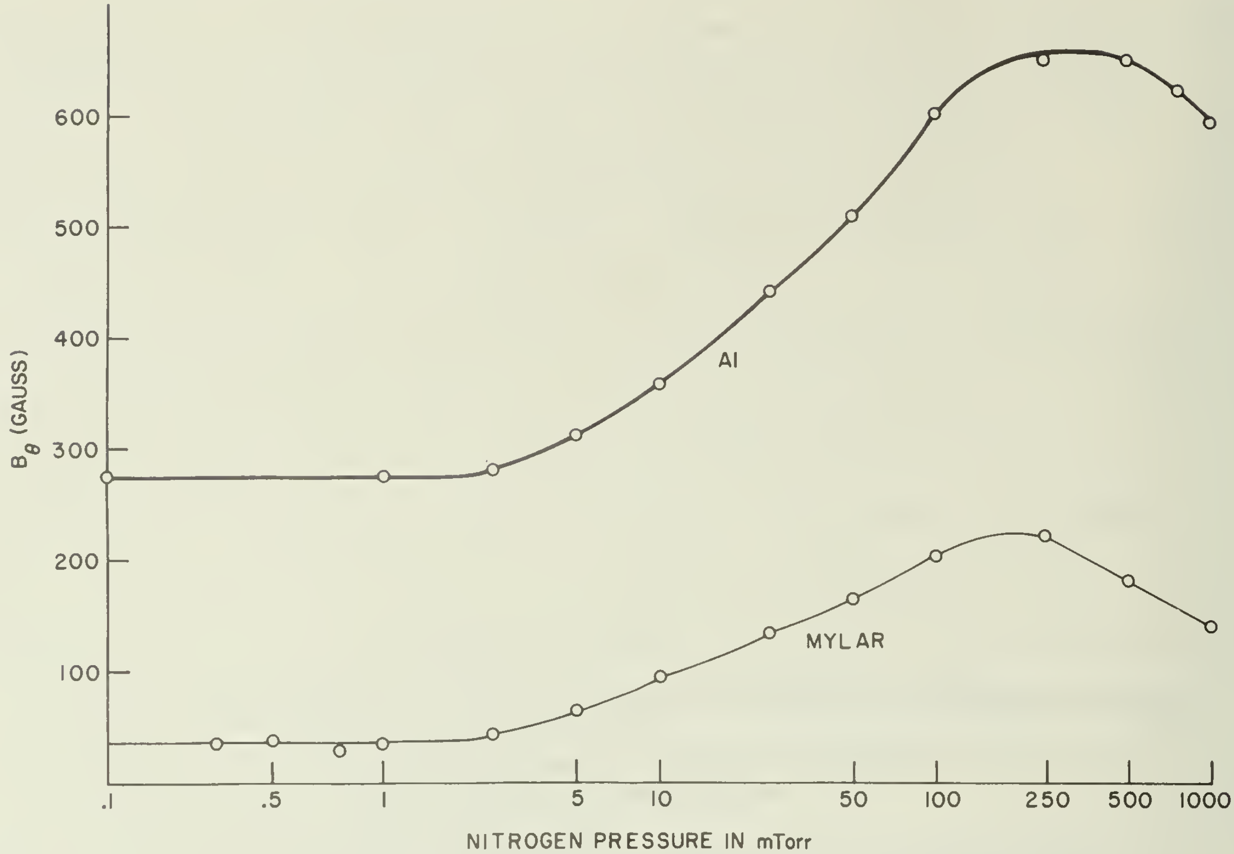

FIG. 1. Maximum azimuthal magnetic field as a function of N_2 background pressure at $r = 0.3$ cm, $\theta = 0°$, and $z = 0.4$ cm for aluminum and Mylar targets.

(~ 1-mm-diam) inductive probes. Electric double probes were used to study the plasma density variations.

The propagation velocity of the laser plasma front, as determined from the electric-double-probe signals, ranged from about 1.5×10^7 cm/sec at 0.1 mTorr N_2 to 3×10^6 cm/sec at 250 mTorr N_2. These velocities were determined by computing the average velocity of the maximum probe signals along the line $r = 0.3$ cm, $\theta = 0°$, for z values from 1.0–2.5 cm. The magnetic fields were primarily azimuthal, symmetric about the z axis, and corresponded to an electron current in the $+z$ direction. For pressures above 250 mTorr N_2 and at distances larger than about $z = 1$ cm, azimuthal magnetic fields are generated at the front of an expanding aluminum-laser plasma, which are in a direction opposite to the initial fields. This phenomenon is currently under investigation.

Figure 1 displays the manner in which the maximum azimuthal magnetic fields, detected at a fixed position, depend on the background pressure of nitrogen for aluminum and Mylar targets. The pressure at which the magnetic field attains its maximum value was found to decrease as the probe was moved out along the line $r = 0.3$ cm, $\theta = 0$. At all positions checked (the closest being $r = 0.3$ cm, $\theta = z = 0$) a pressure dependence was observed. Figure 1 indicates that field amplification depends only on the background gas and that, below about 1 mTorr, the fields are target dependent. The spatial relationship of the magnetic fields to the laser plasma density n_i for an aluminum target and background pressures of 0.1 and 5 mTorr at a time 300 nsec after the arrival of the laser pulse at the target surface is shown in Fig. 2. For the earliest times checked (20 nsec), the maximum fields along this line resided at the front of the expanding laser plasma.

In a previous study,[5] it was observed that, for background pressures above about 30 mTorr, the streaming laser plasma swept up the photoionized background plasma. This snowplowing of the ambient background plasma caused a pileup of the laser plasma. The front thickness δ of the laser plasma was found to scale as the cube root of the background pressure.

The pressure dependence of Fig. 1 shows three regions of behavior. Below about 1 mTorr the fields are pressure independent. In this region the background plasma density appears to be too small to interact with the laser plasma for the scale lengths of this experiment. In the region above 1 mTorr, the coupling of the background with the laser plasma directly influences the source term of Eq. (2). This influence can be shown by writing the source term $\vec{S} = (k/en_e)\nabla T_e \times \nabla n_e$ in the form $k(\nabla T)_r/e\delta$, where $(\nabla T)_r$ is the radial temperature gradient, here in the negative r direction, and $\nabla n_e/n_e \simeq 1/\delta$. The density gradient is in the negative z direction and δ is characteristic of the length over which the density changes. As the background pressure increases, δ decreases, becoming of the order of the shell thickness at the front of the streaming laser plasma. In the region above 250 mTorr, irreversible dissipation of field energy into particle energy is dominant.

In Fig. 2 the fields for a background pressure of 5 mTorr are larger than those for 0.1 mTorr, with the exception of the region from $z = 1.3$ to $z = 1.5$ cm, where the fields for 0.1 mTorr are slightly larger. Thus it appears that magnetic fields have been created along this line. An order-of-magnitude calculation of the classical diffusion time shows it to be much larger than the experimental time so that the increased field at the front does not appear to be the result of field diffusion, but the result of field generation at the front.

From Eq. (2), it follows that the source term reverses its sign if the direction of the pressure gradient is reversed and it should be possible to create azimuthal magnetic fields, in a direction opposite to the initial fields, by reversing the direction of the pressure gradient at late times in the plasma expansion. Magnetic field reversal has been observed several hundred nanoseconds after shut off of the laser pulse. The field reversal was produced by allowing the expanding laser plasma to impinge upon a glass plate placed at $z = 1.15$ cm. The resulting pileup of the plasma caused a rever-

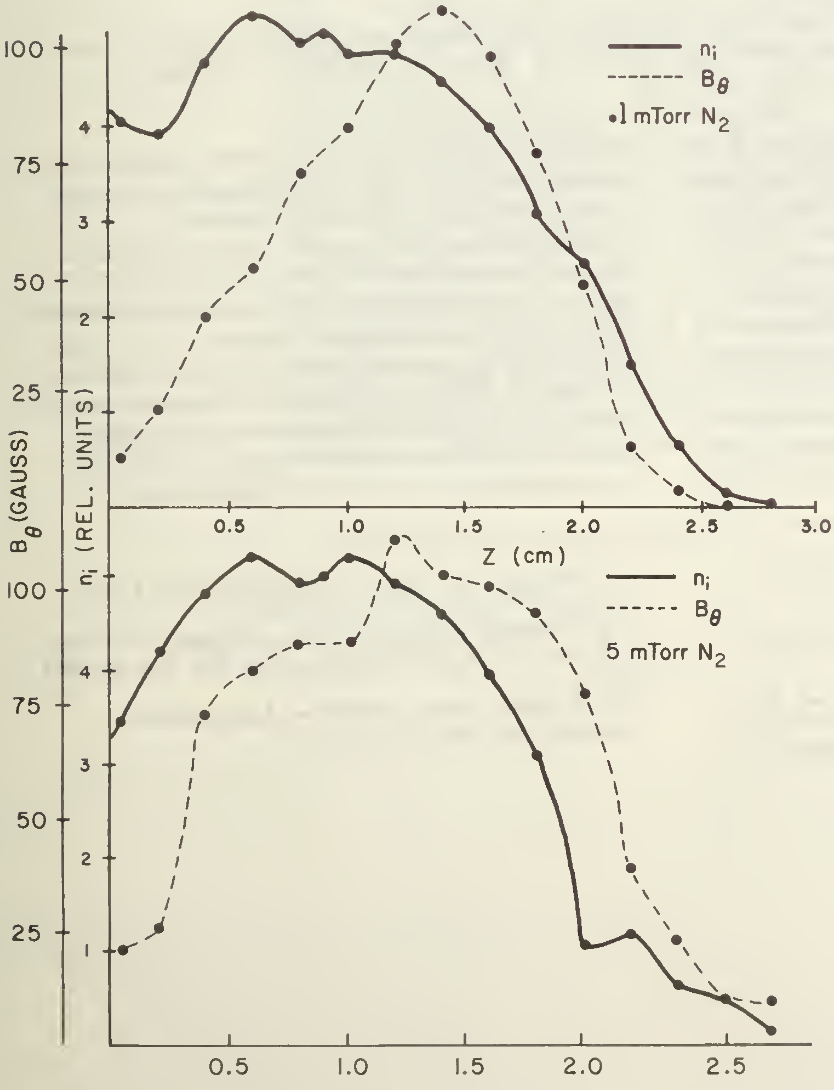

FIG. 2. Relation of B_θ to the plasma density profile n_i along the line $r = 0.3$ cm and $\theta = 0°$, 300 nsec after arrival of the laser pulse, at an aluminum target.

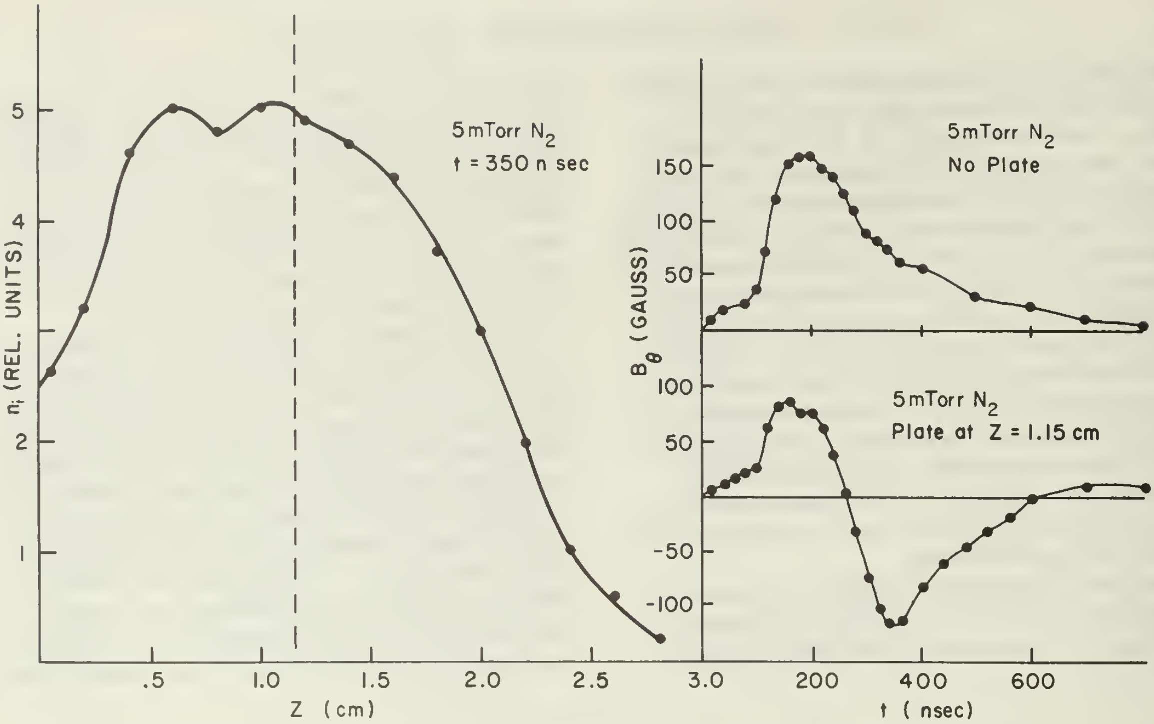

FIG. 3. Plasma density profile along the line $r=0.3$ cm and $\theta=0°$ for an aluminum target; upper-right-hand corner: B_θ at $r=0.3$ cm, $\theta=0°$, $z=1.0$ cm; lower-right-hand corner: B_θ at $r=0.3$ cm, $\theta=0°$, $z=1.0$ cm.

sal of the pressure gradient, a reappearance of the radial temperature gradient, and a corresponding production of azimuthal magnetic fields in a direction opposite to the initial fields. Figure 3 shows the plasma density profile for expansion into a background of 5 mTorr N_2 in the absence of the glass plate. The upper insert shows the azimuthal magnetic fields versus time at the position $r=0.3$ cm, $\theta=0$, $z=1.0$ cm without the glass plate in place, while the lower insert shows the azimuthal fields at the same position but with the glass plate at $z=1.15$ cm and parallel to the target surface. The magnetic field attains its largest negative value at a time $t=350$ nsec, corresponding to the arrival of the front maximum at the plate.

In conclusion, the magnetic fields are found to depend on the background-gas pressure because the background gas influences the pressure gradients in the front of the streaming laser plasma. Also, magnetic fields can be produced long after laser shutoff.

It may be assumed that such a mechanism for the generation of magnetic fields can occur in other streaming plasmas, as for example, in the solar wind encountering the earth's magnetic field.

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Appendix C

ABSTRACT OF PAPER PRESENTED AT THE 1972 ANNUAL MEETING OF THE DIVISION OF PLASMA PHYSICS, MONTEREY CALIFORNIA, 13-16 Nov. 1972

5E10 Self-Generated Magnetic Fields in a Laser Produced Plasma. F. SCHWIRZKE, L. L. McKEE, Naval Postgraduate School - A 300 MW, 20 ns, Nd laser produced a plasma by irradiation of a 0.005 in. MYLAR foil. The dynamics of the plasma and the dependence of the self-generated magnetic fields on position, time, laser power density, and ambient background pressure have been investigated. The B-field is primarily azimuthal with respect to the target normal and symmetric about it. The fields were mapped as function of time showing a toroidal current flow pattern. The B-field is carried along with the expanding plasma and is decaying as function of time. After 150 ns the regular contours of the field start to break up. The strength of the B-field depends quite strongly on the background pressure of N_2. At a given position the field was amplified by a factor of about 6 (38 to 210 gauss) when the pressure was increased from 0.1 to 200 mTorr. The B-field was damped exponentially with further increasing pressure above 200 mTorr. The reason for the amplification seems to be that a larger current can flow through the photo-ionized background plasma. Work supported by AFOSR (MIPR-0004-69) and ONR.

January 1971

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The dependence of the self-generated magnetic fields associated with a laser-produced plasma on position, time, and background pressure has been investigated. The presence of the ambient background is found to influence the generation of the fields during the laser irradiation of the plasma. This influence continues long after laser shut-off and causes the fields to reverse their direction.

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